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Article

Quiet eye training improves surgical knot tying more than traditional technical training. A randomized, controlled study

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RUNNING HEAD: Knot tying training

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Experts consistently exhibit more efficient and effective gaze behaviors, comprised of fewer fixations of longer duration, compared to less expert and novice groups (1, 2). The number of fixations is thought to reflect the information-processing demands placed on the individual, whereas the fixation location reflects the important cues used guiding action. Of particular interest to researchers is the final fixation before the initiation of a critical phase of the movement, termed the quiet eye period (QE) (3). The QE period appears to functionally represent the time needed to organize the neural networks and visual parameters responsible for the precise control of movements (4). The onset of the QE occurs before the critical movement, and the offset when gaze deviates off the location. Both an earlier onset and longer QE duration have been consistently reported to be associated with higher levels of expertise and performance.

Examining gaze and movement-based indices enable us to capture the perceptual and motor mechanisms that underlie efficient action. Gaze and hand movement behavior have previously been examined during several surgical procedures and skills. For example, in a computer-based laparoscopic surgery task, which involved reaching for and touching a small target, expert surgeons reported faster movement times, fewer errors, and longer final fixation on the target location, compared to novices, who fixated the tool and target intermittently (5, 6). Researchers have also examined QE and hand movement times of surgeons with high and low levels of experience during identification and preservation of the recurrent laryngeal nerve during a thyroid lobectomy on a cadaver model (7). Highly experienced surgeons had a longer duration QE on the nerve prior to performing blunt and sharp dissections, providing evidence of greater focus and concentration at critical moments during the operation.

Researchers have also reported differences in QE and hand movement behavior between expert and novice surgeons (8). Expert surgeons not only possess superior knot tying performance and faster movement times, but have a longer QE on the knot prior to the placement phase, compared to novices, who had a higher percentage of fixations on their hands (8).

QE training programs involving the use of video-based expert QE models, video feedback of individual QE characteristics, have been shown to increase QE duration, motor performance and efficiency in a number of tasks (9-14). In addition, virtual laparoscopic trainees in a gaze training group reported higher performance score, faster movement times and longer fixations on the target location, compared to movement training and discovery learning groups (15).

The aim of the study was to examine whether a QE or technical (TT) training program would be lead to increased knot tying performance in one-handed square knots in first year surgical residents. Gaze and hand movement data were recorded during pretest, retention and transfer conditions. It was hypothesized that the QE and TT groups would increase their knot tying performance from pretest to retention and transfer. It was predicted that the QE group would demonstrate a longer QE duration, fewer fixations, and faster hand movement times compared to the TT group in the retention and transfer tests compared to the pretest.

Methods

Participants

Twenty first year surgical residents (age: 26 ± 1.6 years) volunteered for the study. All participants had previously received a half-day of basic knot tying training using the Ethicon knot tying board and manual as part of their surgical skills module. Participants were randomly assigned to either a QE or TT group. All had normal, or corrected to normal vision. Ethics approval was obtained through the University of Calgary Conjoint Health Ethics Research Board.

Equipment

A SensoMotoric Instruments (SMI) ETG eye-tracking system was used to collect gaze and hand movement data. The SMI-ETG is a lightweight (76 g), glasses mounted binocular system that uses dark pupil tracking to measure point of gaze with a spatial resolution of 0.1 degree and temporal resolution of 30 Hz (33.3ms per frame), with a built-in high-definition scene camera. A Simulab Boss knot tying board was used for the pretest and retention, with red markers indicating desired knot placement location placed on the parallel tubing at a separation width of 2 cm (see Figure 1a). An Ethicon knot tying cylinder was used for the transfer test, with a red marker indicating desired knot placement location placed at the center of the hook (see Figure 1b). Both boards were covered with surgical drapes and Ethicon 2-0 Perma-hand silk sutures were used throughout the testing sessions.

Insert Figure 1 here

Procedure

All participants completed a pretest and a training phase, followed by retention and transfer conditions. In all conditions participants were required to tie one-handed square knots with three throws. Before the testing session participants were fitted with the SMI-ETG system and calibrated. The experimental procedure is outlined in Table 1.

Insert Table 1 here

Data management

For each participant the second knot of each condition was coded and analyzed, creating a total of 60 knots per resident. Each knot consisted of three throws and three movement phases (cross, pass, placement). The data were coded using the Quiet Eye Solutions software, which coupled (frame by frame) the surgeon’s fixations and hand movement phases. The dependent variables were: knot tying performance (%), percentage QE duration (%), number of fixations, total movement time (s), and movement phase time (s). Knot tying performance was assessed by a blinded expert surgeon using the Tytherleigh instrument(16), which allows a maximum score was 13 per knot, which was converted to a percentage score. Total movement time was defined as the start of the first cross phase until the end of the final placement phase. QE duration was converted to relative time based on percentage of total movement time. The QE was defined as the final fixation on the knot placement location within 1 degree of visual angle for a minimum of 100 ms prior to each placement phase. Two independent coders carried out coding, with the objectivity of the data being established using intra-observer (99.1%) and inter-observer (97.7%) agreement methods.

Statistical analysis

Knot tying performance, percentage QE duration, number of fixations and total movement time were analyzed using separate 2 x 3 mixed design ANOVAs, with group (QE, TT) as the between-subjects factor and condition (pretest, retention, transfer) as the within-groups factor. Movement phase time was analyzed using a 2 x 3 x 3 mixed design ANOVA, with group (QE, TT) as the between-subjects factor and condition (pretest, retention, transfer) and movement phase (cross, pass, placement) as the within-groups factors. Effect sizes were calculated using partial eta squared values (η_p^2). Greenhouse-Geisser epsilon was used to control for violations of sphericity and the alpha level for significance was set at 0.05 with Bonferroni adjustment to control for Type 1 errors.

Results

Group and condition main effects for all ANOVAs are reported in Tables 2 and 3, respectively.

Insert Tables 2 and 3 here

Knot tying performance (%)

There was a significant group x condition interaction, $F_{2,36}$, = 11.70, $p < 0.001$,

$\eta_P^2 = 0.39$ (see Figure 2). Both the QE and TT groups significantly increased their knot tying performance from pretest to retention, demonstrating that both training methods are effective in improving knot tying performance. However, whilst the QE group maintained a higher knot tying performance in the transfer, the TT group significantly decreased performance from retention to the transfer, although the performance remained significantly higher than the pretest. These results show that the QE training enabled participants to maintain a more effective knot tying performance even in the more complex transfer condition.

Insert Figure 2 here

Quiet eye duration (%)

There was a significant group x condition interaction, $F_{2,36}$, = 15.73, $p < 0.001$, $\eta_P^2 = 0.46$ (see Figure 3). Participants in the QE group significantly increased their percentage QE duration from pretest to retention and transfer, whereas the TT group demonstrated no significant differences between conditions (see supplementary videos). These data demonstrate that the gaze behavior of the technical training group remained unchanged, whereas the QE group increased their QE duration in line with the training, and importantly were able to maintain this behavior in the complex transfer condition.

Insert Figure 3 here

Number of fixations

There was also a significant group x condition interaction, $F_{2,36}$, = 12.54, $p < 0.001$, $\eta_P^2 = 0.41$. There were no significant differences for the TT group from pretest to retention, however the number of fixations increased in the transfer compared to pretest and retention conditions. The QE group demonstrated a greater number of fixations in the pretest compared to retention and transfer. These data demonstrate that the QE training group managed to reduce the amount of fixations, which is indicative of a more efficient visual strategy, and maintain a lower number of fixations in the transfer test. Conversely, the TT group maintained a high number of fixations in the retention, and then increased their fixations in the transfer test. This suggests a more inefficient strategy, which is likely to be a result of an increase in attentional demand.

Total movement time (s)

There was no significant group x condition interaction, $F_{2,36}$, = 1.95, $p = 0.157$, $\eta_P^2 = 0.10$. No significant differences in total movement times were reported for either group from pretest to retention. However, both groups total movement times increased in the transfer test. It is likely that the more complex nature of the transfer task led to the increase in movement time.

Movement phase time (s)

There was a significant main effect for movement phase, $F_{2,36}$, = 64.93, $p < 0.001$, $\eta_P^2 = 0.78$. Movement time was significantly faster in the cross phase compared to the pass and placement phases. Movement time was also significantly faster in the pass compared to the placement phase. As the placement phase is the most important phase of the movement, critical for accuracy and tension of the knot, longer movement time in the placement phase would be expected. There was a significant condition x phase interaction, $F_{4,72}$, = 16.15, $p < 0.001$, $\eta_P^2 = 0.47$ (see Figure 4). Movement time was significantly faster in the pass phase during retention compared to pretest and transfer. Movement time was slower in the placement phase during the transfer compared to pretest and retention phases. Due to the spatial constraints of the transfer task it is unsurprising that longer placements times are reported by both groups.

Insert Figure 4 here

Discussion

The aim of the current study was to examine whether a QE or TT training program would be lead to increased knot tying performance in one-handed square knots. It was hypothesized that after training both the QE and TT groups would increase their knot tying performance and record faster total movement and movement phase times. Additionally, the QE group was expected to demonstrate higher percentage QE duration post training, and compared to the TT group.

Both the TT and QE group significantly improved their knot tying performance from pretest, retention and transfer as a result of the training. However the QE group performed significantly better at the knot tying task compared to the TT group who followed a traditional technical program as determined by independent blinded review of the video tapes. Both total knot tying time and hand movement phases were faster in the QE group compared to TT group. The QE group had a longer QE duration, which was more precisely located on each placement location than the TT. These data suggest that training new surgeons to orientate their QE and focus of attention in a manner similar to expert surgeons not only significantly improves the efficiency and effectiveness of tying knots, but potentially leads to more precise knot placement and lower rates of error. During knot tying, incorrectly placed sutures may result in a knot slippage, unintentional shear force or undue ischemia of tissue, which can lead to knot failure and postoperative hemorrhaging (17, 18). QE training resulted not only in an increase in the technical performance of the knots being tied, but also enhanced focus of attention on anatomical locations critical to operative success.

In line with previous research we found that longer QE durations were associated with more successful performance (19, 20). It is thought that a longer QE duration enables the surgeon more time to accurately organize the movement parameters of the task, which allows a more effective action to be executed (4). It also facilitates an external focus of attention that enables distractions and irrelevant environmental stimuli to be ignored, allowing full attention to the task (21). A longer duration QE also enhances cognitive “slowing down” which Moulton and colleagues found to be characteristic of expert surgeons (7, 22). The expert surgeon cognitively re-focuses and brings an increased level of attention to bear during critical times during an operation. It is important to note that this ‘slowing down’ is a cognitive process, and is not indicative of slower hand movements.

The QE group also reported fewer fixations than the TT group post-training. When the eyes move from one fixation location to another, using rapid eye movements called saccades, visual information is suppressed. Therefore, a larger number of short duration fixations in visual search patterns will decrease the amount of information that is processed. Fixating more areas is a characteristic of novice eye movements. Usually, novices do not know where the relevant cues are in a task environment and therefore use a large number of fixations to scan the whole environment (1). This strategy reduces the amount of information they are accruing from the critical areas of the task, leading to poorer action execution. In the current study, the QE group used few fixations to the final placement location of the knot, which is critical in surgery.

In the transfer test, which involved tying a knot in a more complex location, the QE group demonstrated longer QE duration and fewer fixations compared to the TT group. Researchers have demonstrated that QE duration increases with task difficulty, as more complex actions usually require increased information processing (23). Participants in the QE group maintained a longer QE in the transfer compared to pretest, which enabled them to maintain performance in the more complex condition. In comparison, the TT group was unable to maintain their performance gains during transfer. With increased task requirements, requiring longer movement programming times (24), the TT group employed a less efficient search pattern involving more fixations on their hands, as well as on the sutures. This strategy meant the TT group was unable to accurately execute the movement patterns trained during the study and used in the simpler retention test to maintain performance.

We also found significant group differences in hand movement times. Total movement time was significantly faster for the QE compared to the TT group. Training individuals to use longer QE durations has been reported to enable individuals to organize the movement patterns and allow a more efficient, less conscious movement (12, 14). We corroborate these results by showing that using a QE focus not only improved the effectiveness of the movement (i.e. performance outcome) but also the efficiency (i.e. movement time). We also found differences in movement time among the individual phases (cross, pass, placement). In line with previous research, the participants took longer in the placement, compared to pass, and pass compared to cross phase (8). The TT group spent longer on the placement phase post-training, which has been identified as the critical movement phase, which may have enabled them to improve performance in the retention. Similarly, in the transfer task, the QE group increased their movement time on the placement phase, which may have provided a similar advantage, enabling them to maintain the high performance scores, despite the more complex task. It might also be that knowing a knot is positioned correctly increases confidence and leads to faster movements times. Furthermore, movement time for all hand phases in the retention and transfer test were also longer for the TT compared to the QE group. These data suggest that the improvements in hand movement efficiency are not limited to certain phases, but are evidence of a more global action strategy that results in faster movement throughout the task.

This study has demonstrated the potential use of QE training to improve learning, retention and transfer of surgical skills. Future research should examine the long-term effectiveness of QE training, as well as transfer to the live surgical setting. QE training programs in other areas of medicine and health care could also be explored, especially with the prevalence of simulation training and the need for medical trainees to acquire high levels of skill even as current work restrictions may limit access to adequate volume of training (25).

In summary, we have demonstrated that QE training improved performance at a higher rate and maintained performance effectiveness and movement efficiency in a transfer task, compared to the TT group. To our knowledge, this is the first study to identify the effectiveness of QE training in surgical knot tying. The procedures outlined in the current study could be applied to other skills in surgery thereby potentially leading to a range of performance metrics and expeditions of learning of simple and/or complex surgical skills. These results can be used to integrate QE data into future surgical skills training, and be used as a tool to create more effective training programs in the future.

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Table Captions

Table 1. Experimental procedure for the quiet eye and technical training groups.

Table 2. Group main effects from the ANOVAs for all dependent variables.

* significantly different to quiet eye training group

Table 3. Condition main effects from the ANOVAs for all dependent variables.

* significantly different to pretest

† significantly different to retention

Figure Captions

Figure 1. a) Simulab Boss knot tying board, used for the pretest and retention, with markers indicating desired knot placement location at a separation; b) Ethicon knot tying cylinder, used for the transfer test, with marker indicating desired knot placement location placed at the center of the hook.

Figure 2. Knot tying performance (%; SE) for the quiet eye and technical training groups in the pretest, retention and transfer conditions.

Figure 3. Quiet eye duration (%; SE) for the quiet eye and technical training groups in the pretest, retention and transfer conditions.

Figure 4. Movement phase time (s; SE) for the quiet eye and technical training groups for each of the movement phases in the pretest, retention and transfer conditions.